Naval Postgraduate School
Monterey, California 93943-5138

NPS-09-02-022

SUMMARY OF RESEARCH 2001

Department of Applied Mathematics
Graduate School of Engineering and Applied Sciences

Michael A. Morgan
Chair

Carlos Borges
Associate Chair for Research

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Prepared for: Naval Postgraduate School
Monterey, CA 93943-5000

NAVAL POSTGRADUATE SCHOOL
Monterey, California

RADM David R. Ellison, USN
Superintendent

Richard Elster
Provost

This report was prepared for the Naval Postgraduate School, Monterey, CA.

Reviewed by:

Danielle Kuska
Director, Research Administration

Released by:

David W. Netzer
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13. ABSTRACT (Maximum 200 words.)

This report contains project summaries of the research projects in the Department of Applied Mathematics. A list of recent publications is also included, which consists of conference presentations and publications, books, contributions to books, published journal papers, and technical reports. Thesis abstracts of students advised by faculty in the Department are also included.

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THE NAVAL POSTGRADUATE SCHOOL MISSION

Increase the combat effectiveness of the U.S. and allied forces and enhance the security of the U.S.A. through advanced education and research programs focused on the technical, analytical, and managerial tools needed to confront defense related challenges of the future.

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PREFACE

Research at the Naval Postgraduate School is carried out by faculty in the four graduate schools (School of International Graduate Studies, Graduate School of Operations and Information Sciences, Graduate School of Engineering and Applied Sciences, and Graduate School of Business and Public Policy) and three Research Institutes (The Modeling, Virtual Environments, and Simulation (MOVES) Institute, Institute for Information Superiority and Innovation (I2SI), and Institute for Defense System Engineering and Analysis (IDSEA). This volume contains research summaries for the projects undertaken by faculty in the Department of Applied Mathematics during 2001. The summary also contains thesis abstracts for those students advised by Applied Mathematics faculty during 2001.

Questions about particular projects may be directed to the faculty Principal Investigator listed, the Department Chair, or the Department Associate Chair for Research. Questions may also be directed to the Office of the Associate Provost and Dean of Research. General questions about the Naval Postgraduate School Research Program should be directed to the Office of the Associate Provost and Dean of Research at (831) 656-2099 (voice) or research@nps.navy.mil (e-mail). Additional information is also available at the RESEARCH AT NPS website, http://web.nps.navy.mil/~code09/

Additional published information on the Naval Postgraduate School Research Program can be found in:

- *Compilation of Theses Abstracts:* A quarterly publication containing the abstracts of all unclassified theses by Naval Postgraduate School students.
- *Naval Postgraduate School Research*: A tri-annual (February, June, October) newsletter highlighting Naval Postgraduate School faculty and student research.
- *Summary of Research*: An annual publication containing research summaries for projects undertaken by the faculty of the Naval Postgraduate School.

This publication and those mentioned above can be found on-line at:
http://web.nps.navy.mil/~code09/publications.html.

INTRODUCTION

The research program at the Naval Postgraduate School exists to support the graduate education of our students. It does so by providing military relevant thesis topics that address issues from the current needs of the Fleet and Joint Forces to the science and technology that is required to sustain the long-term superiority of the Navy/DoD. It keeps our faculty current on Navy/DoD issues, and maintains the content of the upper division courses at the cutting edge of their disciplines. At the same time, the students and faculty together provide a very unique capability within the DoD for addressing warfighting problems. Our officers must be able to think innovatively and have the knowledge and skills that will let them apply technologies that are being rapidly developed in both the commercial and military sectors. Their unique knowledge of the operational Navy, when combined with a challenging thesis project that requires them to apply their focused graduate education, is one of the most effective methods for both solving Fleet problems and instilling the life-long capability for applying basic principles to the creative solution of complex problems.

The research program at the Naval Postgraduate School consists of both reimbursable (sponsored) and institutionally funded research. The research varies from very fundamental to very applied, from unclassified to all levels of classification.

- Reimbursable (Sponsored) Program: This program includes those projects externally funded on the basis of proposals submitted to outside sponsors by the School's faculty. These funds allow the faculty to interact closely with RDT&E program managers and high-level policymakers throughout the Navy, DoD, and other government agencies as well as with the private sector in defense-related technologies. The sponsored program utilizes Cooperative Research and Development Agreements (CRADAs) with private industry, participates in consortia with government laboratories and universities, provides off-campus courses either on-site at the recipient command, by VTC, or web-based, and provides short courses for technology updates.

- Naval Postgraduate School Institutionally Funded Research (NIFR) Program: The institutionally funded research program has several purposes: (1) to provide the initial support required for new faculty to establish a Navy/DoD relevant research area, (2) to provide support for major new initiatives that address near-term Fleet and OPNAV needs, (3) to enhance productive research that is reimbursably sponsored, and (4) to cost-share the support of a strong post-doctoral program.

In 2001, the level of research effort overall at the Naval Postgraduate School was 148 faculty work years and exceeded $48 million. The reimbursable program has grown steadily to provide the faculty and staff support that is required to sustain a strong and viable graduate school in times of reduced budgets. In FY2001, over 93% of the research program was externally supported. A profile of the sponsorship of the Naval Postgraduate School Research Program in FY2001 is provided in Figure 1.

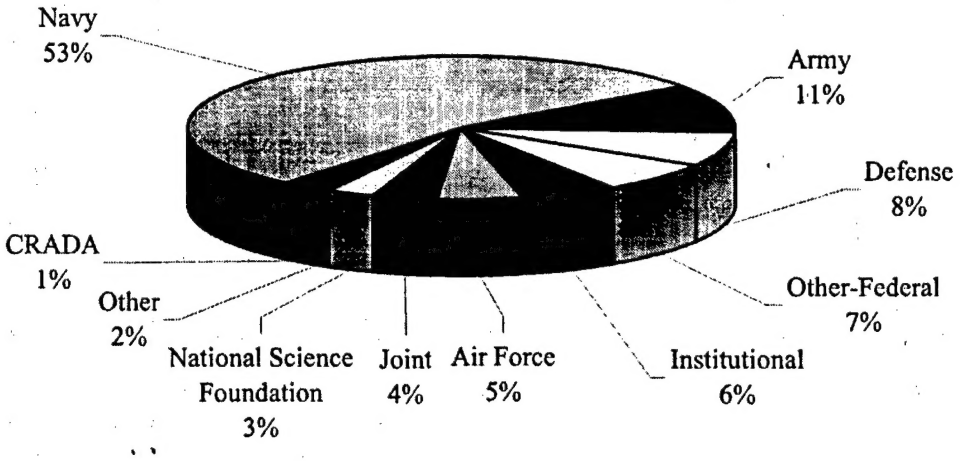


Figure 1. Profile of NPS Research and Sponsored Programs ($52M)

The Office of Naval Research is the largest Navy external sponsor. The Naval Postgraduate School also supports the Systems Commands, Warfare Centers, Navy Labs and other Navy agencies. A profile of external Navy sponsorship for FY2001 is provided in Figure 2.

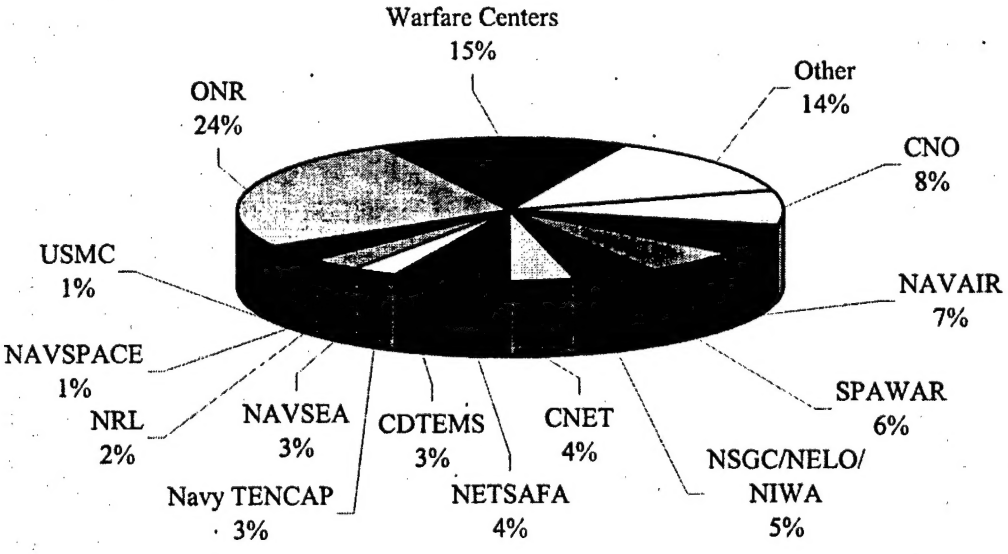


Figure 2. Navy External Sponsors of NPS Research and Sponsored Programs ($29M)

These are both challenging and exciting times at the Naval Postgraduate School and the research program exists to help ensure that we remain unique in our ability to provide education for the warfighter.

DAVID W. NETZER
Associate Provost and Dean of Research

September 2002

DEPARTMENT OF APPLIED MATHEMATICS

MICHAEL A. MORGAN
CHAIR

DEPARTMENT SUMMARY

OVERVIEW:

The NPS Applied Mathematics Department is committed to excellence. Our purpose is to provide an exceptional mathematical education focused on the unique needs of our students, to produce relevant research for our sponsors, and to provide quality service to the community. We further are committed to maintenance of a well-designed curriculum and a supportive environment for our students.

CURRICULA SUPPORTED:

- The majority of the departmental effort is devoted to the service courses offered which support a variety of curricula.

DEGREES GRANTED:

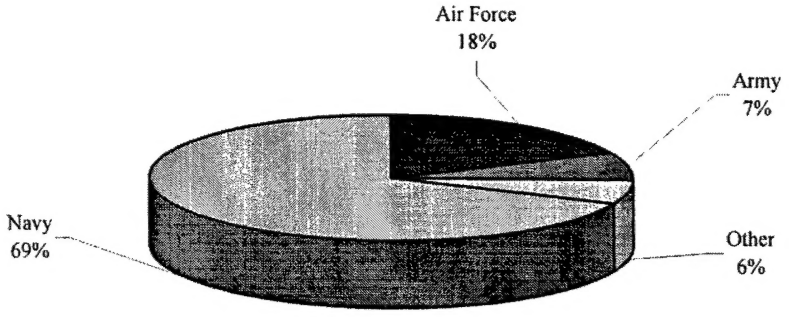
- Master of Science in Applied Mathematics
- Doctor of Philosophy

RESEARCH THRUSTS:

- Scientific Computation
- Control Theory
- Approximation
- Numerical Modeling

RESEARCH PROGRAM (Research and Academic)-FY2001:

The Naval Postgraduate School's sponsored program exceeded $49 million in FY2001. Sponsored programs include both research and educational activities funded from an external source. A profile of the sponsored program for the Department of Applied Mathematics is provided below.



Size of Program: **$271K**

FACULTY LISTING

Morgan, Michael S.
Professor and Chair
MA/Mw
656-2206/2677
mmorgan@nps.navy.mil

Borges, Carlos
Associate Professor and
Associate Chair for Research
MA/Bc
656-2124
borges@nps.navy.mil

Aissen, Michael
Senior Lecturer
MA/Am
656-2714
maissen@nps.navy.mil

Canright, David
Associate Professor
MA/Ca
656-2782
dcanright@nps.navy.mil

Danielson, Donald
Professor
MA/Dd
656-2622
dad@nps.navy.mil

Fahroo, Fariba
Associate Professor
MA/Ff
656-2664
ffahroo@nps.navy.mil

Fredricksen, Hal
Professor
MA/Fs
656-3249
half@nps.navy.mil

Frenzen, Chris
Associate Professor
MA/Fr
656-2435
cfrenzen@nps.navy.mil

Gragg, William
Professor
MA/Gr
656-2194
gragg@nps.navy.mil

Jayachandran, Toke
Professor
MA/Jy
656-2600
tj@nps.navy.mil

Kang, Wei
Associate Professor
MA/Kw
656-3337
wkang@nps.navy.mil

Mansager, Bard
Senior Lecturer
MA/Ma
656-2695
bardman@nps.navy.mil

Neta, Beny
Professor
MA/Nd
656-2235
bneta@nps.navy.mil

Owen, Guillermo
Professor
MA/On
656-2720
owen@nps.navy.mil

Rasmussen, Craig
Associate Professor
MA/Ra
656-2763
ras@nps.navy.mil

Scandrett, Clyde
Professor
MA/Sd
656-2206/2027
cscand@nps.navy.mil

Schoenstadt, Arthur
Professor
MA/Zh
656-2662
alschoen@nps.navy.mil

TOTAL LEAST SQUARES FITTING OF ORDERED DATA WITH POLYNOMIAL SPLINES

Carlos F. Borges, Associate Professor
Department of Applied Mathematics
Sponsor: Unfunded

OBJECTIVE: To develop fast and numerically stable algorithms for fitting polynomial splines to ordered data with minimal error in the total least-squares sense.

SUMMARY: This unfunded effort is a continuing research project. The idea is to fit parametric polynomial spline curves to ordered data to get the best possible fit. Unlike traditional least-squares methods we assume that errors may occur in both the x and y directions. Moreover, we allow the data to be completely general - in particular, it does not have to be functional in nature, it may overlap itself or change directions without restriction. All that is required is an ordered set of points in the plane. A variety of different approaches have been investigated and some very fast and robust algorithms have been developed for solving the problem for a single Bezier curve. These algorithms have been extended to work with B-spline curves with general knot sequences. This past year a paper was submitted on this work to Computer Aided Geometric Design. The paper has been accepted and should appear in 2002.

PUBLICATIONS:

Borges, C.F. and Pastva, T.A., "Total Least Squares Fitting of Bézier and B-Spline Curves to Ordered Data," *Computer Aided Geometric Design*, Vol. 19, No. 4, pp. 275-289, 2002.

DoD KEY TECHNOLOGY AREA: Other (Scientific Computation)

KEYWORDS: Curve Fitting, Data Compression, Approximation Theory

RESEARCH IN THE STRUCTURAL DYMAMIC RESPONSE OF THE RAH-66 COMMANCHE HELICOPTER

Donald A. Danielson, Professor
Department of Applied Mathematics
Sponsors: Comanche Program Office and Naval Postgraduate School

OBJECTIVE: Professor Danielson continued his work in support of ongoing development of the Army's RAH-66 *Comanche* helicopter. Two NPS thesis students supported him. This year he used a finite element code to predict the effects of an explosion inside the forward tailcone of the Comanche.

SUMMARY: The model was based on Comanche structural information from engineers Jason Firko and Mel Niederer, located at Boeing helicopters in Philadelphia. The MSC.Software code Patran was used as the pre and post processor, and the MSC.Software code Dytran as the computational engine. The Catia model was not suitable for meshing, but the geometry therein was transferred to a new group and became the basis for the model. With further study of copies of the large engineering drawings, a faithful replica of the Comanche tailcone was constructed. The final geometry consists of 56 surfaces and 10 solids. The tailcone structure is meshed with 25,261 Lagrangian elements (16,665 2-D shell elements plus 8,596 3-D solid elements) of edge length 1 inch. The fluid region is meshed with 22,113 3-D solid Eulerian elements of edge length 2 inches. The model has 5 different 2-D orthotropic materials, which are used to construct the laminate composites for the shell elements. It also uses an aluminum material for some shell elements. The vents' shell elements are modeled with an extremely weak material, so that the inner surface forms a closed volume (required in Dytran). A 3-D orthotropic material is assigned to the solid Lagrangian elements. Material properties of air are assigned to the Eulerian elements. Generic (unclassified) initial properties are used for the sphere containing the blast wave. A job was run and graphical results were inserted into the final report.

PUBLICATIONS:

Danielson, D.A., "Comanche Tailcone Model Documentation," Naval Postgraduate School Report, sent to Boeing, 2001.

THESIS DIRECTED:

Gorak, M. and Libby, J., "Finite Element Modeling of the RAH-66 Comanche Tailcone Section Using Patran and Dytran," Masters Thesis, Naval Postgraduate School, June 2001.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Modeling and Simulation

KEYWORDS: Helicopters, Airframes, Explosions, Computer Software

EFFICIENT TRAJECTORY OPTIMIZATION

Fariba Fahroo, Associate Professor
Department of Applied Mathematics
Sponsor: Draper Labs

OBJECTIVE: The objectives of this research are to explore spectral patching techniques, their accuracy, and efficiency for solving both continuous and discontinuous trajectory optimization problems.

SUMMARY: This research produced a numerical method for solving complex trajectory optimization problems in a rapid manner. The spectral patching method developed advances the state of the art in trajectory optimization by providing solutions that are provably optimal. In this project, the spectral patching method was developed and implemented in MATLAB. A numerical package called DIDO, which was based on the numerical method was developed and a launch problem among other examples from astronautics were solved using the package.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Space Vehicles, Modeling and Simulation

KEYWORDS: Spectral Patching Techniques, Trajectory Optimization

DEPLETION LENGTHS IN SEMICONDUCTOR NANOSTRUCTURES

Chris Frenzen, Associate Professor
Department of Applied Mathematics
James Luscombe, Professor
Department of Physics
Sponsor: Unfunded

OBJECTIVE: In this research a formula for the depletion length in a cylindrical nanostructure was developed, and investigated in various asymptotic limits. It was shown that the standard formula for depletion lengths at a planar semiconductor interface underestimates the depletion length in nanostructures of finite radius.

SUMMARY: The depletion, W(R), at the surface of a cylindrical nanostructure of radius R is calculated and shown to satisfy a certain inequality which bounds W(R) below by W_p and above by W_p times the square root of two, where W_(p) is the depletion length at a planar interface. The standard result W_p is shown to underestimate the depletion length in a finite structure. The discrepancy between W_p and W(R) becomes significant when the dimensions of the structure become comparable to the depletion length, as can occur in nanostructure devices. This work has been accepted for publication in the journal *Solid State* and will appear in 2002.

PUBLICATIONS:

Frenzen, C., "Depletion Lengths in Semiconductor Nanostructures," *Solid State Electronics*, Vol. 46, pp. 885-889, 2002.

DoD KEY TECHNOLOGY AREAS: Manufacturing Science and Technology (MS&T)

KEYWORDS: Semiconductor Nanostructures, Depletion Length

EFFICIENT NONLINEAR TRANSIENT DYNAMIC ANALYSIS FOR STRUCTURAL OPTIMIZATION USING AN EXACT INTEGRAL EQUATION FORMULATION

Joshua Gordis, Associate Professor
Department of Mechanical Engineering
Beny Neta, Professor
Department of Applied Mathematics
Sponsor: National Science Foundation

OBJECTIVE: The focus of this phase of the project is the development of an improved solution algorithm for fast transient analysis of large, locally nonlinear structures using time domain structural synthesis.

SUMMARY: Time domain structural synthesis is a general and exact formulation for transient problems in structural modification, substructure coupling, and base excitation. The formulation is characterized by the governing equation of the synthesis, which is a nonlinear Volterra integral equation. The governing equation makes use of impulse response functions calculated for those coordinates of the (sub) structures subjected to forces of synthesis (e.g. modification forces, coupling forces). This physical coordinate formulation provides for a largely unrestricted and exact model reduction, in that only those coordinates of interest need be retained in the synthesis. The development of several algorithms intended to improve upon the original algorithm developed by Gordis are documented.

The last algorithm developed meets the stated goals of the project. This algorithm is a newly developed recursive, block-by-block convolution solution to the governing nonlinear integral equation. As is demonstrated with a simple but realistically large nonlinear base excitation problem (51,500 DOF finite element model), the new algorithm provides a 78% reduction in time required for the nonlinear transient base excitation solution, as compared with traditional direct integration calculated using a widely-used commercial finite element program. This very large savings in computer time is obtained for a single analysis, i.e. assuming no prior calculations have been made for the impulse response functions of the (sub) structures. The new algorithm provides an even greater reduction in computer time for all subsequent analyses. As shown in the example problem, once all required impulse response functions have been calculated, the nonlinear base isolation solutions calculated using the new recursive, block-by-block convolution algorithm take approximately 7 seconds, as compared with the direct integration solution, which takes approximately 30 minutes. This rapid reanalysis capability will facilitate the development of numerical optimization for the design of nonlinear isolation.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Finite Elements, Structural Synthesis, Convolution, Block-By-Block, Adaptive

COORDINATED FORMATION AND ATTITUDE CONTROL OF MULTI-SATELLITE SYSTEMS

Wei Kang, Associate Professor
Department of Applied Mathematics
Sponsor: Air Force Research Laboratory and Naval Postgraduate School

OBJECTIVE: The objectives of the project are (1) design robust feedbacks that meet the needs of attitude control and coordination; (2) identify some attitude stabilization and attitude tracking problems that is useful for satellite formation missions; (3) selection of key parameters to build a perceptive frame; (4) reference projection design, and hybrid control architecture design for the purpose of coordinated control; (5) simulation and lab test of the control design.

SUMMARY: The PI visited AFRL on WPAFB three times to collaborate with the AFRL research team in this subject. The design algorithm based on perceptive frame developed in NPS and MSU is combined with an H-infinity optimal attitude controller to coordinate multiple satellites. Two conference papers and a journal paper from this project were published or accepted during October 2000-September 2001. One more journal paper was submitted.

PUBLICATIONS:

Kang, W., Xi, N. and Sparks, A., "Theory and Applications of Formation Control in a Perceptive Referenced Frame," *Proceedings IEEE Conference on Decision and Control*, Sydney, Australia, 12-15 December 2000.

Kang, W., Yeh, H.H. and Sparks, A., "Coordinated Control of Relative Attitude for Satellite Formation," *Proceedings AIAA Guidence, Navigation, and Control Conference*, 6-9 August 2001.

Kang, W. and Yeh, H.H., "Coordinated Attitude Control of Multi-Satellite Systems," *International Journal of Robust and Nonlinear Control*, Vol. 12, pp. 185-205, 2002.

Nelson, E., Sparks, A. and Kang, W., "Coordinated Nonlinear Tracking Control for Satellite Formations," *Proceedings AIAA Guidence, Navigation, and Control Conference*, 6-9 August 2001.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Space Vehicles, Modeling and Simulation

KEYWORDS: Attitude Control

VISIBLE SETS AND ITS MANUFACTURING APPLICATIONS

Wei Kang, Associate Professor
Department of Applied Mathematics
Sponsor: Ford Scientific Research Lab and Naval Postgraduate School

OBJECTIVE: The focus of this project for the year of 2001 is on the production planning based on information feedback. Mathematical model of production planning integrating both statistical data and IT based fast information feedback is developed.

SUMMARY: An index theory was developed for the proposed problem. It numerically interprets the visibility of each side of a mechanical part. Dynamical programming is applied with the index theory to minimize the number of sensor locations to inspect every surface of a mechanical part. Also funded by Ford Scientific Lab, the Robotics Lab of MSU is building up a system with robot arms, sensors and softwares. The theory developed in this project will be implemented in the lab, and the entire system will be tested using real auto parts from the sponsor.

PUBLICATIONS:

Kang, W. and Song, M., "Manufacturing Planning Based on Information Feedback," *Proceedings 6th International Conference on Control, Automation, Robotics and Vision,* Singapore, 5-8 December 2000. (Best Paper Award, 6th International Conference on Control, Automation, Robotics and Vision, Singapore, 5-8 December 2000.)

DoD KEY TECHNOLOGY AREAS: Computing and Software, Manufacturing Science and Technology (MS&T)

KEYWORDS: Production Planning

GALERKIN SPECTRAL SYNTHESIS METHODS

Beny Neta, Professor
Department of Applied Mathematics
Sponsor: Unfunded

OBJECTIVE: To develop existence and uniqueness theory for the energy dependent, steady state neutron diffusion equation with inhomogeneous oblique boundary conditions imposed. Also to develop a convergence theory for the Galerkin Spectral Synthesis Approximations.

SUMMARY: An existence and uniqueness theory is developed for the energy dependent, steady state neutron diffusion equation with inhomogeneous oblique boundary conditions imposed. Also, a convergence theory is developed for the Galerkin Spectral Synthesis Approximations which arise when trial functions depending only on energy are utilized. The diffusion coefficient, the total and scattering cross-sectional data are all assumed to be both spatially and energy dependent. Interior interfaces defined by spatial discontinuities in the cross-section data are assumed present. Our estimates are in a Sobolev-type norm, and our results show that the spectral synthesis approximations are optimal in the sense of being of the same order as the error generated by the best approximation to the actual solution from the subspace to which the spectral synthesis approximations belong.

DoD KEY TECHNOLOGY AREAS: Computing and Software

KEYWORDS: Galerkin, Spectral Synthesis, Diffusion

ORBIT DETERMINATION

Beny Neta, Professor
Department of Applied Mathematics
Sponsor: Unfunded

OBJECTIVE: To develop a method for trajectory propagation that better reflects the energy consumption of the system.

SUMMARY: In this work a method was developed for the solution of the equations of motion of an object acted upon by several gravitational masses. In general, the motion can be described by a special class (for which y_ is missing) of second order initial value problems (IVPs).
Y''(x) = f(x, y(x)), y(0) = y0, y'(0) = y'0.
The numerical integration methods for this can be divided into two distinct classes:

(a) problems for which the solution period is known (even approximately) in advance;
(b) problems for which the period is not known.

Here only some methods of the second class were considered. Numerical methods of Runge-Kutta type as well as linear multi-step methods can be found in the literature. Our idea here is to develop a new method that conserves the energy per unit mass in the case of perturbation-free right and use the energy in

other cases to approximate the angular variation. The generalization to cases were the energy is not conserved is given. Numerical experiments for both cases were computed and the solution to well established methods was compared.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Space Vehicles, Modeling and Simulation

KEYWORDS: Orbit Determination, Numerical Algorithms

DEPARTMENT OF APPLIED MATHEMATICS

2001
Faculty Publications and Presentations

PUBLICATIONS/PRESENTATIONS

JOURNAL PAPERS

Fahroo, F. and Ross, I.M., "A Second Look at Approximating Differential Inclusions," *Journal of Guidance, Control and Dynamics,* Vol. 24, No. 1, pp. 131-133, 2001.

Fahroo, F. and Ross, I.M., "Costate Estimation by a Legendre Pseudospectral Method," *Journal of Guidance, Control and Dynamics*, Vol. 24, No. 2, pp. 270-277, 2001.

Gordis, J.H. and Neta, B., "Fast Transient Analysis for Locally Nonlinear Structures by Recursive Block Convolution," *ASME Journal of Vibrations and Acoustics*, Vol. 123, pp. 545-547, 2001.

Kaminer, I., Kang, W., Yakimenko, O. and Pascoal, A.M., "Application of Nonlinear Filtering to Navigation System Design Using Passive Sensors," *IEEE Transactions on Aerospace and Electronic Systems*, Vol. 37, pp. 158-172, 2001.

Kang, W., Sparks, A. and Banda, S., "Coordinated Control of Multi-Satellite Systems," *AIAA Journal of Guidance, Control and Dynamics,* Vol. 24, No. 2, pp. 360-368, 2001.

Knorr, J.B. and Neta, B., "Plotting Circularly Polarized Field Patterns Using Processed NEC 4 Output Files," *Applied Computational Electromagnetic Society Newsletter*, Vol. 16, No. 2, pp. 26-33, 2001.

CONFERENCE PUBLICATIONS

Chang, D.E., Kang, W. and Krener, A.J., "Normal Forms and Bifurcations of Control Systems," *Proceedings of the IEEE Conference on Decision and Control,* Sydney, Australia, 12-15 December 2000.

Hamzi, B. and Kang, W., "Resonant Terms in a Class of Systems with Stationary Bifurcation," *Proceedings of the IEEE Conference on Decision and Control,* Orlando, FL, 4-7 December 2001.

Hamzi, B., Kang, W. and Barbot, J.P., "On the Control of Hopf Bifurcations," *Proceedings of the IEEE Conference on Decision and Control*, Sydney, Australia, 12-15 December 2000.

Kang, W. and Song, M., "Manufacturing Planning Based on Information Feedback," *Proceedings of the 6th International Conference on Control, Automation, Robotics and Vision,* Singapore, 5-8 December 2000.

Kang, W., Xi, N. and Sparks, A., "Theory and Applications of Formation Control in a Perceptive Referenced Frame," *Proceedings of the IEEE Conference on Decision and Control,* Sydney, Australia, 12-15 December 2000.

Kang, W., "Normal Forms, Invariants and Bifurcations of Nonlinear Control Systems," *Proceedings of the 3rd Workshop of Nonlinear Control Network, Bifurcation and Control,* Kloster Irsee, Germany, 1-3 April 2001.

Kang, W., Yeh, H. and Sparks, A., "Coordinated Control of Relative Attitude for Satellite Formation," *Proceedings of the AIAA Guidence, Navigation, and Control Conference*, 6-9 August 2001.

Nelson, E., Sparks, A. and Kang, W., "Coordinated Nonlinear Tracking Control for Satellite Formations," *Proceedings of the AIAA Guidence, Navigation, and Control Conference*, 6-9 August 2001.

Neta, B. and Ilan-Lipowski, Y., "A New Scheme for Trajectory Propagation," *Proceedings AIAA/AAS Astrodynamics Specialist Conference*, Quebec City, Quebec, Canada, Paper Number AAS 01-446, 31 July-3 August 2001.

Ross, I.M., Yan, H. and Fahroo, F., "A Curiously Outlandish Problem in Orbital Mechanics," ASS/AIAA Astrodynamics Specialist Conference, Paper AAS 01-430, Quebec City, Quebec, Canada, 30 July–22 August 2001.

Ross, I.M. and Fahroo, F., "A Pseudospectral Transformation of the Covectors of Optimal Control Systems," *Proceedings of the First IFAC/IEEE Symposium on System Structure and Control*, Prague, Czech Republic, August 2001.

Ross, I.M. and Fahroo, F., "Convergence of Pseudospectral Discretizations of Optimal Control Problems," *Proceedings of the Fortieth Conference on Decision and Control*, Orlando, FL, December 2001.

Yan, H., Fahroo, F. and Ross, I. M., "Optimal Feedback Control Laws by Legendre Pseudospectral Approximations," *Proceedings of the American Control Conference 2001,* Arlington, VA, June 2001.

Xiao, M. and Kang, W., "Bifurcation Control Using Integral Averaging Method," *Proceedings of the IEEE Conference on Decision and Control,* Sydney, Australia, 12-15 December 2000.

CONFERENCE PRESENTATIONS

Mansager, B., "A Combat Simulation Analysis of Autonomous Legged Underwater Vehicles," Second Joint Australian/American Conference on the Technologies of Mine Countermeasures, Randwick Army Barracks, Sydney, Australia.

Mansager, B., "The Utility of Fire and Forget Technology Demonstrated Using 1-meter Terrain," Sixty Ninth Military Operations Research Society Symposium, U.S. Naval Academy, Annapolis, MD.

BOOKS

M. J. Holler and G. Owen, eds., *Power Indices and Coalition Formation*, Boston (Kluwer), 2001.

CHAPTERS IN BOOKS

Owen, G., "Game Theory," *International Encyclopedia of the Social & Behavioral Sciences*, N.J. Smelser and Paul B. Baltes, eds., Pergamon, Oxford, pp. 5863-5868, 2001.

DEPARTMENT OF APPLIED MATHEMATICS

Thesis Abstracts

AN ALGORITHM FOR ENUMERATING THE NEAR-MINIMUM WEIGHT *S-T* CUTS OF A GRAPH

Ahmet Balcioglu-First Lieutenant, Turkish Army
B.S., Turkish Army Military Academy, 1993
Master of Science in Operations Research-December 2000
Advisors: R. Kevin Wood, Department of Operations Research
Craig W. Rasmussen, Department of Mathematics
Second Reader: Gerald G. Brown, Department of Operations Research

An algorithm for enumerating near-minimum weight *s-t* cuts in directed and undirected graphs, with applications to network interdiction and network reliability is provided. "Near-minimum" means within a factor of $1+\varepsilon$ of the minimum for some $\varepsilon \geq 0$. The algorithm is based on recursive inclusion and exclusion of edges in locally minimum-weight cuts identified with a maximum flow algorithm. A polynomial-time complexity result when $\varepsilon = 0$, and for $\varepsilon > 0$ the demonstration of good empirical efficiency is proven. The algorithm is programmed in Java, run on a 733 MHz Pentium III computer with 128 megabytes of memory, and tested on a number of graphs. For example, all 274,550 near-minimum cuts within 10% of the minimum weight can be obtained in 74 seconds for a 627 vertex 2,450 edge unweighted graph. All 20,806 near-minimum cuts within 20% of minimum can be enumerated in 61 seconds on the same graph with weights being uniformly distributed integers in the range [1,10].

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Near-Minimum Cuts, Cut Enumeration, Minimum Cuts, Network Interdiction

REVISITING THE BATTLE OF THE LITTLE BIG HORN

Matthew J. Burns-Lieutenant, United States Navy
B.S., Naval Postgraduate School, 2000
Master of Science in Defense Analysis-December 2000
Advisors: Gordon H. McCormick, Special Operations Academic Group
Bard Mansager, Department of Mathematics

The Battle of the Little Big Horn has captured the interest of historians, scholars, and military enthusiasts since the day that over 200 United States soldiers under General George Armstrong Custer's command were decimated by Crazy Horse and 2000 Indian warriors. Competing theories regarding the details of the battle have arisen, mostly due to conflicting first hand accounts.

The purpose of this thesis is twofold. The first purpose is to perform an historical analysis of the Battle of the Little Big Horn, using war-gaming. A series of controlled, comparative simulations of the battle will be carried out using the Synchronization Matrix, a war-gaming tool obtained from U.S. Army Field Manual (FM) 101-5. This analysis will evaluate three competing theories and interpretations of the battle, with the objective of categorizing the theories by degree of plausibility. The second purpose is to examine the impact of alternative notional leadership decisions on the outcome of the battle, e.g. what if Custer had not split his force? The result is a confirmation that war-gaming can indeed be utilized for the study of historical combat, as well as for future planning.

DoD KEY TECHNOLOGY AREAS: Other (Primitive Technology)

KEYWORDS: War-Gaming, Course of Action Analysis

LOSSLESS COMPRESSION USING BINARY NECKLACE CLASSES AND MULTIPLE HUFFMAN TREES

William L. Crowley, Jr.-Captain, United States Army
B.S., Campbell University, 1991
Master of Science in Applied Mathematics-June 2001
Advisor: Harold M. Fredricksen, Department of Applied Mathematics
Second Reader: Craig W. Rasmussen, Department of Applied Mathematics

In this thesis, we present two lossless compression approaches. Our Rotational Tree Approach (RTA) is based upon mathematics developed by Fredricksen. RTA uses the rotations associated with binary necklace classes to disperse source bit strings to a forest of Huffman encoding trees. Our Indexed Tree Approach (ITA) also uses a Huffman forest, but disperses bit strings via a simpler mechanism based upon the first few bits of each string. For text compression, we find RTA to be competitive with standard Huffman encoding while ITA is generally superior by a small margin of 1% – 3%. Both approaches owe their (limited) success to decreased modeling overhead as compared to standard Huffman encoding. Compression results against the Canterbury Corpus test suit and complete Java implementation code are included as appendices.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Lossless Data Compression, Discrete Mathematics, Analysis of Algorithms, Huffman coding, Rotational Tree, Index Tree

FINITE ELEMENT MODELING OF THE RAH-66 COMANCHE HELICOPTER TAILCONE SECTION USING PATRAN AND DYTRAN

Mark S. Gorak-Captain, United States Army
B.S., Marquette University, 1991
Master of Science in Applied Mathematics-June 2001
and
Jeffrey A. Libby-Captain, United States Army
B.S., United States Military Academy, 1991
Master of Science in Applied Mathematics-June 2001
Advisor: Donald A. Danielson, Department of Applied Mathematics

The United States Army contracted Boeing-Sikorsky to develop the RAH-66 Comanche, a new, armed reconnaissance helicopter that features stealth technology designed to improve survivability when operating in hostile environments. Ballistic testing is required on any new technology, to include the Comanche, prior to fielding. Computer-based simulations are being employed to reduce the requirements for expensive live fire testing. This thesis uses computer programs called PATRAN and DYTRAN from MSC Software Corporation to build the model and simulate the effects of an explosive round detonating in the Comanche tailcone section. This thesis describes in great detail the process of creating and modifying the model in PATRAN to most accurately depict the Comanche tailcone section and creating the input decks for DYTRAN to run the analysis. A test case involving an explosion with a high amount of explosive energy, or specific internal energy (SIE) was simulated. From this test, several results are shown to display the capabilities of DYTRAN. These results, when compared with live fire data, can be used to validate the computer-based simulation in order to reduce the requirements of expensive live fire testing.

DoD KEY TECHNOLOGY AREA: Air Vehicles, Computing and Software, Materials, Processes, and Structures, Modeling and Simulation

KEYWORDS: Comanche, Ballistic Modeling, PATRAN, DYTRAN, Tailcone

A NUMERICAL STUDY OF FUEL-OPTIMAL LOW-EARTH-ORBIT MAINTENANCE

Lawrence E. Halbach-Major, United States Air Force
B.A.E.M., University of Minnesota, 1988
Master of Science in Astronautical Engineering-December 2000
Advisors: I. M. Ross, Department of Aeronautics and Astronautics
Fariba Fahroo, Department of Mathematics

This thesis studies the fuel optimal periodic reboost profile required to maintain a spacecraft experiencing drag in low-earth-orbit (LEO). Recent advances in computational optimal control theory are employed, along with a Legendre-Gauss-Lobatto Pseudospectral collocation code developed at the Naval Postgraduate School, to solve the problem. Solutions obtained by this method are compared against a previous study. Key issues were checking the optimality of the solutions by way of the necessary conditions and the behavior of the solution to changes in the thruster size. The results confirmed Jensen's findings of propellant savings of one to five percent when compared against a middle altitude Forced Keplerian Trajectory (FKT). Larger savings are predicted if compared against a finite-burn Hohmann transfer with drag. The costates estimates compared favorable against necessary conditions of Pontryagin's Minimum Principle. Analysis of the switching function yielded periods of thrust-modulated arcs. The optimal thrust profile appears to be a thrust-modulated burn to raise the orbit followed by an orbital decay and a terminating thrust-modulated arc. For a sufficiently low thrust-control authority, the switching structure includes a maximum thrust arc. Indirect optimization techniques to confirm these findings were unsuccessful.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Orbital Mechanics, Optimization, Optimal Control Theory, Orbit Maintenance

A COMPREHENSIVE STATISTICAL ANALYSIS OF SUBSTANCE ABUSE PATTERNS AND TRENDS WITHIN THE UNITED STATES ARMY

Kevin P. Romano-Captain, United States Army
B.S., University of Utah, 1992
Master of Science in Applied Mathematics-June 2001
Advisor: Toke Jayachandran, Department of Applied Mathematics
Second Reader: Lyn R. Whitaker, Department of Operations Research

The United States Army's Center for Substance Abuse Programs relies on a broad based approach to combat substance abuse. Certain factors, however, have been associated with a soldier's involvement with substance abuse. They include age, race, gender, military occupation specialty, and rank.

A statistical analysis of recent drug and alcohol use/abuse patterns would permit the Army to target services and programs toward those most at risk for developing substance abuse related problems. Additionally, a model that could profile the typical enrollee into the Army's Substance Abuse Program, ASAP, would be a valuable predictive mechanism for future abuse trends within the Army.

This study supports the United States Army's Center for Substance Abuse Programs' efforts to improve the identification of those most at risk for substance abuse. This study provides a detailed statistical analysis on current substance abuse patterns within the United States Army and civilian society, and presents a mathematical model of ASAP enrollments.

DoD KEY TECHNOLOGY AREAS: Biomedical, Manpower, Personnel and Training

KEYWORDS: Substance Abuse, Alcoholism, Drug Abuse, DUI, DWI, United States Army, Cluster Analysis, Time Series

COMPUTERIZED BALLISTIC MODELING OF THE COMANCHE TAILFAN SHROUD

Allen H. Stephan-Captain, United States Army
B.S., United States Military Academy, 1991
Master of Science in Aeronautical Engineering-December 2000
Advisors: E. Roberts Wood, Department of Aeronautics and Astronautics
Donald A. Danielson, Department of Mathematics

The U.S. Army has contracted Boeing-Sikorsky to develop the RAH-66 Comanche, a new, armed reconnaissance helicopter that features stealth technology designed to improve survivability when operating in hostile environments. Ballistic testing is required on the Comanche prior to fielding. Computer based simulations are being employed in order to reduce requirements for expensive live-fire testing. This thesis uses a computer program called Dytran from MacNeal-Schwendler to simulate the effects of an explosive round detonating in the Comanche tailfan shroud. Six test cases involving explosions with varying amounts of explosive energy, or specific internal energy, are evaluated. From these tests, a curve showing the percentage of structural failure versus the specific internal energy is plotted. Assuming that 20% structural failure of the model equates to a catastrophic failure, this analysis shows that the analyzed section of the Comanche tailfan shroud can withstand an explosion with a specific internal energy of $2.58 * 10^{10}$ in^2/sec^2. Any potential threat rounds with specific internal energies greater than $2.58 * 10^{10}$ in^2/sec^2 will pose serious threats to the Comanche.

DoD KEY TECHNOLOGY AREAS: Air Vehicles, Materials, Processes and Structures, Modeling and Simulation

KEYWORDS: Comanche, Ballistic Modeling, Dytran, Tailfan Shroud

ATTRACTOR BASINS OF VARIOUS ROOT-FINDING METHODS

Bart D. Stewart-Captain, U.S. Army
B.S., United States Military Academy, 1993
M.S., Troy State University, 1997
Master of Science in Applied Mathematics-June 2001
Advisor: David Canright, Department of Applied Mathematics
Second Reader: Carlos F. Borges, Department of Applied Mathematics

Real world phenomena commonly exhibit nonlinear relationships, complex geometry, and intricate processes. Analytic or exact solution methods only address a minor class of such phenomena. Consequently, numerical approximation methods, such as root-finding methods, can be used.

The goal is, by making use of a variety of root-finding methods (Newton-Rhapson, Chebyshev, Halley and Laguerre), to gain a qualitative appreciation on how various root-finding methods address many prevailing real-world concerns, to include, how are suitable approximation methods determined; when do root finding methods converge; and how long for convergence?

Answers to the questions were gained through examining the basins of attraction of the root-finding methods. Different methods generate different basins of attraction. In the end, each method appears to have its own advantages and disadvantages.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Basin of Attraction, Numerical Methods, Complex Polynomials

REDUCING NON-MONOTONICITIES IN COMBAT MODELS

William C. Vinyard-Major, United States Marine Corps
B.A., University of Colorado, Boulder, 1988
Master of Science in Operations Research-September 2001
Advisors: Thomas W. Lucas, Department of Operations Research
Carlos F. Borges, Department of Mathematics
Paul J. Sanchez, Department of Operations Research

Non-monotonic behavior in combat models is an important topic to those using the output of such models as a basis for decision making. These decisions can be complicated by non-monotonic behavior in the combat models. This paper examines the Dewar model which exhibits non-monotonic behavior caused by the chaos inherent in its structure. Previous papers have examined only small subsets of this 18 dimensional combat model. The combinatorial possibilities of main effects and interactions among the 18 dimensions are too great to examine en masse. Consequently, there are three goals. First, systematically explore the Dewar model for additional non-monotonic behavior. Second, determine the effect of stochastic modeling on the non-monotonic behavior of the Dewar model response surface. Third, develop a method for measuring non-monotonicity in the response surface generated by the model. Latin Hypercube Sampling discovers non-monotonicity across broad regions of the model's phase space, and in multiple measures of effectiveness. Stochastic perturbation of model parameters has a dramatic effect on the non-monotonicity of the response surface. Stochastic perturbation can both reduce and exacerbate the non-monotonic behavior of the response surface. If done properly, stochastic modeling can significantly improve the interpretability of the response surface.

DoD KEY TECHNOLOGY AREAS: Modeling and Simulation

KEYWORDS: Non-Monotonic Behavior in Combat Models, Dewar Model, Stochastic Perturbation, Latin Hypercube Sampling

MAGNETIC FIELD ESTIMATION USING OPTIMAL LOCATIONS OF NEAR FIELD SENSORS

Stacey W. Yopp-Lieutenant, United States Navy
B.S., United States Naval Academy, 1994
Master of Science in Applied Mathematics-June 2001
Advisor: Michael A. Morgan, Department of Applied Mathematics
Second Reader: Wei Kang, Department of Applied Mathematics

The objective of this thesis is to theoretically investigate optimal placement of magnetic field sensors near the surface of a submarine in order to predict the magnetic field at a greater distance and reduce error in off board field predictions.

A steel spheroidal shell of uniform thickness with a distribution of magnetic dipoles on the center axis is used to model a submarine. The dipoles inside the shell and induced magnetization in the material of the shell both contribute to the magnetic fields everywhere in space. Computer simulations are preformed in two stages using Matlab programming. The first stage is to compute the magnetic fields using spherical harmonic expansions in each of the three regions. The expansion coefficients are found by enforcing continuity of the tangential fields and normal flux density at the inner and outer boundaries of the shell. The second stage of the simulation adds noise to the computed vector fields at the hypothetical sensors located just outside the shell and uses the noisy "measured" fields to estimate the expansion coefficients in the exterior region. The estimated coefficients are used to construct a predicted field at larger distances from the shell. Accuracy of this method is evaluated by comparison of the predicted and original computed fields.

DoD KEY TECHNOLOGY AREAS: Sensors, Surface/Under Surface Vehicles – Ships and Watercraft, Modeling and Simulation

KEYWORDS: Magnetic Signature, Spheroidal Magnetic Shell, Optimal Field Estimation

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